aries, nor in the directions of the axes which lay indifferently to each other as well as to the milky nucleus which appeared in the section as a lot of air bubbles of different size.

I venture to hope that my attempt will call forth similar researches and would be glad if any other might have a chance to conserve or to study some bigger or more peculiar hailstones than I, and in this way improve our deficient notions about the origin of hail and the details of its formation.

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A SPECULATION IN CRYSTALLOGRAPHY

The conception of six systems of crystallization, which has been prevalent for nearly a century, has doubtless impressed many students of the subject as somewhat arbitrary. Especially does it appear so when it assumes four axes for the hexagonal system and only three for each of the others. To be sure, these axes are simply lines of reference, and the systems are ingeniously formulated so as to include all possible forms, which can be produced by the regular arrangement of particles having uniform size and similar shape in each particular case. While the scheme of classification is comprehensive and practical, it has really no more foundation in nature than the Linnean orders and families of plants.

The real misuse of these systems, however, has been when the crystallographic axes have been assumed to correspond to molecular bonds, or to similarly related axes in each molecule of a given substance, so that the molecules of a crystal are conceived to be arranged in straight lines corresponding to these axes. While this idea, which is often used in text-books, may be helpful in the explanation of crystals and of crystalline forms, yet it can readily be shown to be arbitrary and unnatural and therefore liable to mislead.

The purpose of this paper is to outline a more rational explanation of crystal structure, constancy of angles, cleavage and other physical properties.

If we should use globules of uniform size to represent molecules, or ultimate particles of an isometric substance, and allow them to take their most compact form, as they would by their mutual attraction, or under the influence of uniform external pressure, they would not arrange themselves in lines corresponding to rectangular axes, as is so often indicated in crystallographic diagrams and models. Instead of each one touching its neighbor at *six* points, as it would in that case, it touches at *twelve* points. Nature often shows a similar fact in the globular cells of organic tissues. When such are crowded together until the intervening spaces are obliterated, each cell takes the form of a *rhombic dodecahedron.*

We, therefore, take this form as a promising suggestion and look at it more carefully. We see that if we draw lines through the centers of opposite planes, or, if with globules compactly arranged, we draw lines through the centers of each and through opposite points of contact, each will be traversed by six lines, and if space be filled with such dodecahedrons, or with equal-sized globules, such space will be traversed with straight lines running in six directions. Every such line, or axis, will form an angle of 60° with four of the others and 90° with the sixth.

If space permitted, we might show that by assuming such an arrangement of isometric molecules all the different planes of that system may be as logically derived as they can be from the commonly postulated arrangement parallel with rectangular axes. Starting with a single molecule, if we should add successive layers of similar molecules equally in all directions, the result would be a rhombic dodecahedron. If the obtuse interfacial angles, eight in number, were modified by one plane, because of some variation of molecular attraction, or because of different density of the generating solution, octohedral planes would appear. If, on the other hand, the acute angles, of which there are six, should be similarly modified, we should have cubic planes, and so on through all the forms of the isometric system.

But, as we should naturally expect from the

very diverse chemical formulæ of different substances, we find many forms varying more or less from those of the isometric system. Nevertheless, so long as molecules are exactly similar to each other and are arranged in their most compact form, as they will be if given time to adjust themselves to their mutual attractions, each molecule will touch its neighbors at twelve points just as surely as in the case of the isometric, but the six lines passing through their points of contact will be no longer at the constant angles of 60° and 90°, but at varying angles. The angles between the lines in which the molecules are arranged in the mass will correspond strictly with the lines joining the points of contact in each molecule; hence we may limit our thought to a single molecule.

TABLE OF POSSIBLE DISTORTIONS OF THE RHOMBIC DODECAHEDRON AND RESULTING CRYSTALLOGRAPHIC SYSTEMS

Number of Modification.	Axes.		Corresponding System.	Planes Corresponding Nearly to Dodecahedral Planes.
	Constant.	Varying.		
1	6	0	I	Dodecahedron
2	5	1	O	Basal pinacoid Macro-pinacoid Pyramidal
3	4	2 equal, near 60°	M	Clino-pinacoid Clino-dome Prismatic Hemi-orthodome
4	4	2 equal, near 90°	T	Prismatic Pyramidal
5	4	2 unequal, near 90°	O	Macro-pinacoid Brachy-pinacoid Pyramidal
6	4	2 unequal, near 60°	Tri	Macro-pinacoid Macro-domes Prisms Hemi-brachydomes
7	3	3 equal, near 60°	H	Rhombohedral Prismatic
8	3	3 equal, near 60° and 90°	M	Basal Ortho-pinacoid Pyramidal
9	3	3 unequal, 1 and 2, 60° and 90°	M	Clino-pinacoid Clino-dome Prism Hemi-orthodome
9′	3	3 unequal, 1 and 2, 60° and 90°	Tri	Basal and macro-pinacoids Prisms and brachy-pinacoid Tetra-pyramid
10	3	3 unequal, 1 and 2, 60°	Tri	Basal and macro-pinacoids Brachy-domes and pinacoids Tetra-pyramid
11	3	3, all unequal, 60°	Tri	———
12	3	3, all unequal, 60° and 90°	Tri	———
(4)	2	4 equal, near 60°	T	As in 4
(3)	2	4 equal, near 60° and 90°	M	As in 3
(10)	2	4 unequal, 1 and 3, 60°	Tri	As in 10
(9)	2	4 unequal, 1 and 3, 60° and 90°	M or Tri	As in 9
13	2	4 unequal, 1, 1 and 2, 60°	M or Tri	———
14	2	4 unequal, 1, 1 and 2, 60° and 90°	Tri	———
15	2	4, all unequal	Tri	———
(2)	1	5, all equal	O	As in 2
(5 or 6)	1	5, 1 and 4	O or Tri	As in 5 or 6
(11 or 12)	1	5, 1, 1 and 3	Tri	As before
(15)	1	5, 1, 1, 1 and 2	Tri	As before
18	1	5, all unequal	Tri	———

If its form be that of a prolate spheroid with its poles equidistant from three of the axes, then those axes will be drawn as it were toward the poles and the lengths of these axes will be greater than of the other three. If the poles are midway between four of the axes, they will be similarly drawn together and elongated. If the molecule is an oblate spheroid, corresponding axes will be repelled and shortened. These cases will readily be seen to belong to the hexagonal, or rhombohedral, and the tetragonal systems; in the first two, with the vertical axis longer than the lateral, and in the last two, with the vertical shorter.

Some of the variations will not be regular or symmetrical, yet they may all be shown to correspond to some one of the six recognized crystallographic systems. The following table will indicate the possible variations and the systems into which they would fall, and also some other points. It is to be taken as suggestive rather than exhaustive.

Concerning hemihedral forms, we seem to obtain no more light from this conception than from the older view.

The apparent advantages resulting from this discussion may be briefly stated as follows:

1. It affords a rational explanation of the various phenomena and characteristics of crystals. Given equal and similar particles and simple attractions for each other, which attraction follows the laws conceived to govern gravitation, with the time and freedom for adjustment of particles in the most compact form, and crystals with constant angles and similar cleavage along similar planes, will necessarily result.

2. This recognition of the fundamental relation of the rhombic dodecahedron, which rests on mathematical principles, explains, also, why the kinds of symmetry found in crystals are only the two-, three-, four- and six-fold, for these are factors of twelve. We find why no five-, seven- or other fold will occur.

J. E. TODD

LAWRENCE, KAN.,
June 16, 1910

THE TWENTY-SECOND ANNUAL MEETING OF THE GEOLOGICAL SOCIETY OF AMERICA. II

The Upper Cayugan of Maryland: T. POOLE MAYNARD, Atlanta, Ga. (Introduced by W. B. Clark.)

The Upper Cayugan of Maryland occurs in two well-defined areas in the western part of the state, the Hancock and Cumberland areas, and crosses the state in a northeast-southwest direction, following the general trend of the Appalachians. The rocks constituting the Upper Cayugan consist, usually, of argillaceous, thin-bedded limestones at the bottom, passing gradually into the heavier bedded limestones of the Lower Helderberg. These limestones lie between the Salina below and the Coeymans above and have an average thickness of one hundred and ten feet. There is only a gradual change in lithology from the Salina to the Coeymans and no well-defined lithological break exists. The upper and lower limits of the rocks constituting the Upper Cayugan are determined on paleontological grounds. These rocks, while equivalent in Maryland to the Manlius and Cobleskill of New York, can not be subdivided in Maryland on either paleontological or lithological grounds. The Rondout is absent in Maryland, while the fauna of the Cobleskill and Manlius are not distinct and separate as they are in New York, but they intermingle, typical New York Manlius and Cobleskill forms occurring together. They are also associated with forms occurring in the Upper Decker Ferry of New Jersey.

Discussed by A. W. Grabau.

Stratigraphic Relations of the Livingston Beds of Central Montana: R. W. STONE and W. R. CALVERT, Washington, D. C. (Introduced by M. R. Campbell.)

The Livingston formation occurring at Livingston, Montana, has been described as resting unconformably on the Laramie and overlain by the Fort Union formation. Its age has been considered to be post-Laramie and it has been correlated with the Denver formation of Colorado, partly on lithologic similarity, both formations being composed largely of tufaceous beds. This paper showed that the Laramie of the Livingston and Little Belt Mountains folios of the Geologic Atlas of the United States is Eagle, or at least lower Montana, and that there is no unconformity between it and the overlying Livingston beds in the area under discussion. It showed also that on the west and south sides of the Crazy Mountains about 7,000 feet of sediments, mainly andesitic tuffs,